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An analysis of agent-based approaches to transport logistics

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Abstract

This paper provides a survey of existing research on agent-based approaches to transportation and traffic management. A framework for describing and assessing this work will be presented and systematically applied. We are mainly adopting a logistical perspective, thus focusing on freight transportation. However, when relevant, work of traffic and transport of people will be considered. A general conclusion from our study is that agent-based approaches seem very suitable for this domain, but that this still needs to be verified by more deployed system.

Keywords: Multi-agent systems; Decentralized systems; Survey; Traffic and transportation management

1. Introduction

The research area of agent technology continues to yield techniques, tools, and methods that have been applied or could be applied to the area of traffic and transportation management. The aim of this paper is to present a consistent view of the research efforts made in this area.

We are mainly adopting a logistical perspective, thus focusing on transportation rather than traffic, and on freight rather than people. In particular, we will not survey the extensive work

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on agent-based modeling of driver and commuter behavior. Also we will not consider approaches to supply-chain management.

In the next section, the areas where agent technology may be useful will be identified. We then present a framework that will be used to classify and assess the research in the area. This is followed by a systematic survey of the work found in the literature. Finally, we analyze our findings and present some conclusions.

2. Background

The development of distributed and heterogeneous systems, such as software for automation of, and decision support for logistics management, poses significant challenges for system developers. Agent technology (Weiss, 1999; Wooldridge, 2002) aims to provide new concepts and abstractions to facilitate the design and implementation of systems of this kind. Parunak (1999) lists the following characteristics for an ideal application of agent technology:

- *Modular*, in the sense that each entity has a well-defined set of state variables that is distinct from those of its environment and that the interface to the environment can be clearly identified.
- *Decentralized*, in the sense that the application can be decomposed into stand-alone software processes capable of performing useful tasks without continuous direction from some other software process.
- *Changeable*, in the sense that the structure of the application may change quickly and frequently.
- *Ill-structured*, in the sense that all information about the application is not available when the system is being designed.
- *Complex*, in the sense that the system exhibits a large number of different behaviours which may interact in sophisticated ways.

As most transport logistics applications actually fit Parunak's characterization rather well, this would suggest that agent technology indeed is a promising approach for this area. However, it is not suitable for all applications. For instance, in applications that are monolithic, centralized, static, well-structured, and simple, agent technology will probably not provide any added value, only unnecessary complexity.

3. Evaluation framework

For each paper surveyed we describe the problem studied, the approach taken to solve it, and assess the results.

3.1. Problem description

Each problem description includes the following three parts: the domain studied, the mode of transportation, and the time horizon considered.

3.1.1. Domain

We have chosen to divide the problem descriptions into three domains: *transport*, *traffic*, and *terminal*. A transport is an activity where something is moved between point A and B by one or several modes of transport. Problem areas that fall under the category transport are e.g., route planning, fleet management, different sorts of scheduling, i.e., functionalities that takes place to support transportation.

While transport refer to the movement of cargo from one point to another, traffic refers to the flow of different transports within a network. One train set is thus a transport, or part of a transport, that takes part in the train traffic flow. Hence, a transport can be part of several traffic networks (air, waterborne, road, rail) and a traffic network constitutes of several transports. Typical traffic activities are traffic flow scheduling such as railway slot allocation, air traffic management, and railway traffic management.

Within for example a transport chain where the cargo is transported by truck, rail, ship, and truck again, there are interfaces between the different modes. These interfaces represent nodes for reloading and are referred to as terminals. Terminals can be any fixed place where the cargo is handled and require access to different kinds of resources. Typical terminal activities are resource allocation and scheduling of cranes, forklifts and parts of a facility.

3.1.2. Transport mode

There are five basic modes of transportation: *road*, *rail*, *air*, *water*, and *pipeline* (Stock and Lambert, 2001). Although the use of pipelines often offers the cheapest method in transporting bulk fluids in long distances, we will in this paper not regard this modality.

The water transport via sailing vessels offers one of the most used and less costly means of transporting bulk goods. The use of rail is often associated with bulk items transported less costly than road to far distant markets. The flexibility and often-inevitable use of road for the beginning or final transport mode in a transportation chain makes this the most often used form of transport. Road transport is often associated with faster delivery in short distances and is attractive to shippers and customers that demand choice and flexibility in scheduling. Finally, air transport mode offers the fastest means of transport and usually the most expensive. This mode is usually reserved for high-valued goods that need to be transported across large distances. The use of air is also considered in short supply times, as in the case of disaster relief.

All freight transport modes can include, for example, fleet management techniques, route, and maintenance planning, on-board loading/unloading techniques and on-board computers. In all cases, the emphasis will be on the impact on organizational costs and service levels. Usually in freight logistics, transportation represents the most important single element in logistics costs for most firms (Ballou, 1999). Transportation is a key decision area within logistics due to, on average, a higher percentage of logistics costs associated with this activity than any other logistics activity (Ballou, 1999). The selection of which mode of transport is to be used is dependent on several factors associated with the type of cargo/goods, e.g., requirements on speed, handling, costs, distance, flexibility etc.

Intermodal transportation, refers to "movement of goods in one and the same loading unit or vehicle that uses successively several modes of transport without handling of the goods themselves in changing modes" according to the definition of The European Conference of Ministers of

Transport (ECMT, 2001). The definition is valid also for personal travelling that includes two or more different modes of transportation.

One of the primary challenges in intermodal transport management is to coordinate several interdependent activities within the transport as well as the communication between the multiple actors involved.

3.1.3. Time horizon

Historically, the term logistics referred mainly to issues regarding technical and physical flows of products on an *operational* level. Today, the term includes both strategic and tactical issues beside the operational ones and includes the information flow connected to the physical flow. Therefore, the applications and concepts studied and presented are divided into levels of time perspective; *strategic, tactical*, and *operational* level of decision-making. This is an established classification that is widely used. It can also be seen as a hierarchy in decision time (Schneeweiss, 1999). We will here by *time horizon* refer to at what stage in the decision-making process the application is used, or is intended to be used. There are two dimensions often distinguished, the level of decision-making and its time frame. There is no definite line of separation, but strategic decision-making typically involves long-term decisions concerning determining what to do, while tactical deals with medium-term issues of setting up an action-list, and operational how to conduct the work set out in more specific terms, i.e., short term issues (Shillo and Vierke, 2000). The time horizon for these levels is highly domain dependent.

In this study we also include the execution of tasks and real-time controlling functionalities within the operational decision-making. For a transport operator, as an example, a strategic issue to address would be where to locate distribution centres, while a tactical issue would be to tailor the vehicle fleet to satisfy the customer demands, and the operational level would involve scheduling of each and every transport and the controlling function with monitoring and ad-hoc planning if necessary.

As can be seen there is no established definition on time frame or content in the different planning hierarchy, and it is highly dependent on what type of business that is addressed.

3.2. Approach

Each approach is described by the following three parts: the intended usage of the agent system, the type of agents used, and the type of coordination chosen.

3.2.1. Usage

The applications studied can be classified, according to this paper, as either to serve as an automation system, or a decision-support system. An *automation* system can be defined as ''having a self-acting mechanism that performs a required act at a predetermined time or in response to certain conditions'' (McGraw-Hill Encyclopedia of Science & Technology, 2003). In this context it refers to a system's ability to act upon its decisions, i.e., it has a direct influence on the controlled environment and there is no human involved. On the contrary, a *decision-support system*, DSS, has only at most an indirect impact on the decision-making. A DSS is a system that provides output of some specified type to support the decision process for the user. The user, i.e., the decision-maker, takes the suggested decision(s) into consideration, and then acts. Thus, the final decision is made by a person, not the software system.

3.2.2. Coordination (control, structure, and attitude)

Researchers in many fields including computer science, economy, and psychology have studied the area of coordination, which can be viewed as "managing the interdependencies among activities" (Malone and Crowston, 1994). In any environment where software agents participate, the agents need to engage in cooperative and/or competitive tasks to effectively achieve their design objectives. From the multi-agent systems perspective coordination is a process in which agents engage in order to ensure that a community of individual agents acts in a coherent manner (Nwana et al., 1996). Coordination techniques are classified here according to the three dimensions control, structure, and attitude.

We capture the authority relationships between agents in the dimension of *control*, which is either centralized or distributed (decentralized). The *MAS structure* corresponds to the set of agents constituting the MAS, their roles, and the communication paths between agents. The structure is either predetermined, i.e., static (the set of agents or their roles do not change during the execution), or is changing dynamically. Finally, the *agent attitude* dimension captures the behavior of agents, which is classified as either benevolent (cooperative), i.e., they will comply with social laws and global goals, or selfish (competitive), where the agents' individual goals, e.g., in a market-based economy, will govern their behavior.

3.3. Results

The main classification of the result of the approaches will be in terms of maturity of the research. However, we will also try to assess the performance and the limitations of the approaches.

3.3.1. Maturity

Agent applications can have varying degree of maturity, i.e., how complete and validated an application is. According to Parunak (2000), the description of the maturity of an agent application helps the users to assess how much work that remains to carry out the implementation of the agent application. Furthermore, Parunak has suggested a number of degrees of maturity which formed the basis for our refined classification.

The lowest degree of maturity in the classification is *conceptual proposal*. Here the idea or the principles of the proposed application is described with its general characteristics, e.g., if the model is simple or complex. In the literature the term *conceptual model* is quite well-established and well-defined. However, we prefer the more open term conceptual proposal since it otherwise could be more difficult to fit in all applications according to the classification.

The next level in the classification is *simulation experiments*. Here the application has been tested in a simulation environment. The data used in the simulated experiment can either be real data, i.e., taken from existing systems in the real world, or data that is not real, i.e., artificial, synthetic or generated. Further, the type of data has been divided into limited/partial or full-scale data. The full-scale data represents data for a whole system, while the limited/partial data only covers parts of the system.

Field experiment indicates that experiment with the application has been conducted in the environment where the application is supposed to be applied. As in the simulated experiment, the field experiment is also divided into limited/partial and full-scale. The final level, *deployed* *system*, indicates that the system has been implemented in the real world and also has been or is in use. This is the most mature type of agent applications.

3.3.2. Evaluation comparison

If a new approach is developed to solve a problem which has been solved previously using other approaches, the new approach should be compared to those existing approaches. Such an evaluation could be either *qualitative*, by comparing the characteristics of the approaches, or *quantitative*, by different types of experiments.

3.4. Summary of framework

Table 1 summarizes the framework for describing and assessing the agent-based approaches to logistics. Appendix A provides a table listing the published work in the area of agent-based approached to transport logistics that we have encountered is classified according to this framework. The papers in the table are first sorted according to domain and then according to mode of transportation. In the case where several papers have been published regarding the same project, we have chosen the most recent publication and/or the most widely available.

4. Analysis of survey

The survey shows that agent technology has been applied to many different problem areas within transport logistics. Often these agent approaches are distributed and very complex by nature, such as: planning and scheduling, fleet management, transport scheduling, traffic management, and traffic control. In the work reviewed, there was an even distribution between the three do-

Table 1
Classification framework

	Aspect	Categories
Problem description	Domain	1. Transport, 2. Traffic, 3. Terminal
	Transport mode	1. Air, 2. Rail, 3. Road, 4. Sea, 5. Intermodal
	Time horizon	1. Operational, 2. Tactical, 3. Strategical
Approach	Usage	1. Automation system, 2. Decision support system
	Control	1. Centralized, 2. Distributed
	MAS structure	1. Static, 2. Dynamic
	Agent attitude	1. Benevolent, 2. Selfish
Results	Maturity	1. Conceptual proposal 2. Simulation experiment 2.1. Artificial data, 2.1.1. Limited, 2.1.2. Full-scale 2.2. Real data, 2.2.1. Limited, 2.2.2. Full-scale 3. Field experiment, 3.1. Limited, 3.2. Full-scale 4. Deployed system
	Evaluation comparison	1. None, 2. Qualitative, 3. Quantitative

mains (transport, traffic, and terminal), whereas the modes of transportation were dominated by air, road, and intermodal. It is worth noting that very little work has been done studying strategic decision-making. In addition, only a few of the publications concerning air and rail deal with transport-centered issues. In Fig. 1, the distribution of modal focus over the domains can be seen. Fig. 2 shows the number of applications per mode that have addressed strategic, tactical and/or operational aspects.

Most of the *rail*-related publications address problems of allocating slots for the railway network, i.e., timetabling. This is a problem seldom found within the other modes of transport besides air traffic (even though railway slot allocation differs significantly from air traffic slot allocation). Market-based approaches (Clearwater, 1996) have appealed to several of the researchers, where the coordination mechanism is very similar to the negotiation that takes place in practice. In addition, some publications study resource allocation for specific rail transports, but these problems are not modal-specific to the same extent as the slot allocation problem. Several of

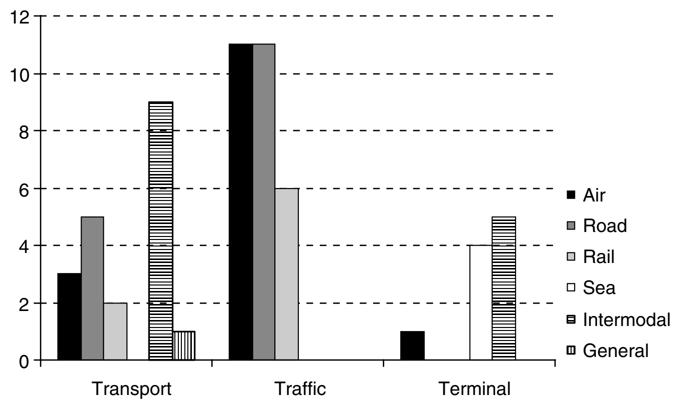

Fig. 1. Problem description: distribution of domain and transport mode.

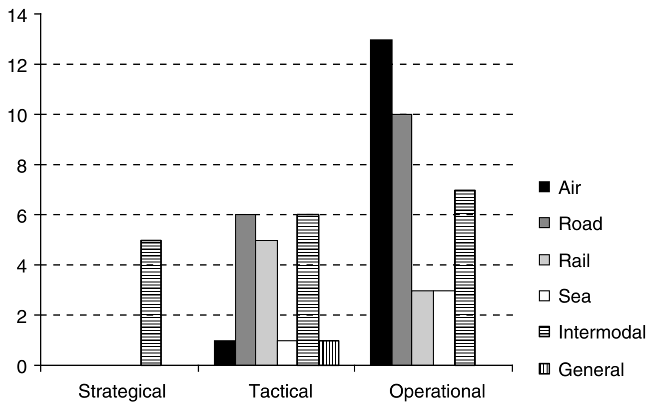

Fig. 2. Problem description: distribution of transportation mode and time horizon.

the approaches have been evaluated experimentally, but no deployed system has been found. Methods that are alternative to agent technology for these kinds of problems are often centralized optimization and simulation technologies.

Regarding the publications that relate to air traffic and transportation, the studies on air traffic management is dominating and agent technology seems to have been applied to this problem area for more than a decade. The main topic addressed is distributed air traffic management using free flight, i.e., the aircrafts are allowed to choose their speed and path in real-time and air traffic restrictions are only applied when air space separation is required. Just one application focusing on airport slot allocation for a tactical setting has been found, which is surprising as many railway scheduling applications exist. Only a few publications in the air domain deal with transport related issues.

In the papers on *road transports*, most of the problems concern transport scheduling, i.e., allocating transport tasks to vehicles. The approaches are distributed and include negotiation in various manners, such as the contract net protocol, and sometimes they are market-based. However, also Multi-Agent Based Simulation (MABS) is used in some applications. The agents in these applications represent different roles, e.g., a company, a truck, a customer etc. The transport applications are on a tactical level and the purpose is most often to serve as a DSS to a transport operator since the problem is complex and need some human supervision before the final transport task allocation. Alternative methods to agent technology in road transport are classical mathematical methods and operations research.

In the *road traffic* domain most of the problems concern traffic management and control to deal with for example congestion of the roads. The applications are designed to inform drivers about the traffic situation and give recommendations, regulate the traffic with signals and messages, and so on. A couple of the applications deal with public transport management where the actual status of the vehicles is compared to the planned status, e.g., a timetable. The majority of the systems are on the operational level and most of the applications function as a DSS, but some are designed to serve as automation systems. Alternative methods mentioned in the papers, are evolutionary algorithms, knowledge-based systems, neural networks, and fuzzy theory.

Concerning the sea mode of transportation, most application of agents have been trying to increase the efficiency of the container terminal operations. Many papers tend to focus specifically at the marine-side interface whilst disregarding the other processes in the terminal that determine overall terminal performance, e.g., the stacking of containers. The terminals are characterized as complex and dynamic systems and researchers find the relationships between the many actors involved having both common and conflicting goals, in which vast amounts of information are not processed adequately to encourage the use of agents. Several papers focus exclusively on the operational processes of communication between the gantry cranes and the straddle carriers in order to reduce idle time and the number of times that a container is handled, whereas a couple of papers deal with tactical and strategic decisions. Unfortunately, the majority of the papers reviewed do not state clearly the type of agent approaches used or how their agents are able to communicate and make decisions. Interestingly, within the sea mode of transportation, most research has focused primarily on the terminal domain with very few papers considering the traffic and transport domains.

Of the reviewed publications regarding *intermodal* transportation, primarily the combination of road and rail has been considered. The problems studied are usually to coordinate several tasks for a specific transport, such as slot request, terminal handling and allocating transport services. The approach is typically to identify a set of different roles, similar to the real-world functions, and allocate agents for each of these. Although only a few publications were found, the work in this area seems to be extensive at the moment and rapidly developing. Some alternative methods for these problems are discrete-event simulation and optimization. In practice, however, they are more often dealt with in an ad-hoc manner with a mix of human-intervention and spread-sheet analysis. For this domain, as for the other domains, the benefits of using agent-based approaches are not explicitly discussed.

The main reasons mentioned in the papers for adopting an agent-based approach are: facilitates distributed control, ability to cope with partial and noisy data, and ability to model complex problems. Although the ability to distribute control is the most cited reason, it is interesting to note that 30% of the projects surveyed make use of centralized control. Also, only half of the applications utilize the possibility of dynamic MAS structures, which is an often cited strength of agent technology. A majority of the work (64%) concerns the use of agent technology in decision support systems. Figs. 3 and 4 illustrate the distribution of the approaches taken for decision support systems and automation systems respectively (two systems are both decision support and automation systems).

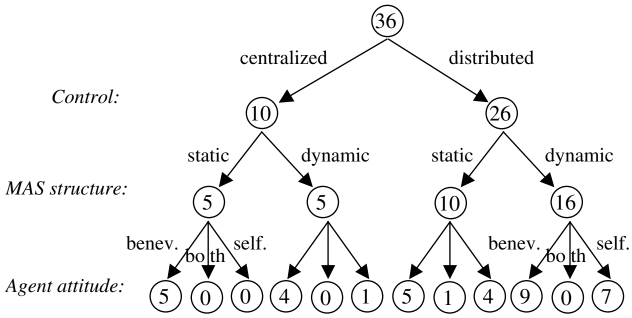

Fig. 3. Number of approaches to decision support systems.

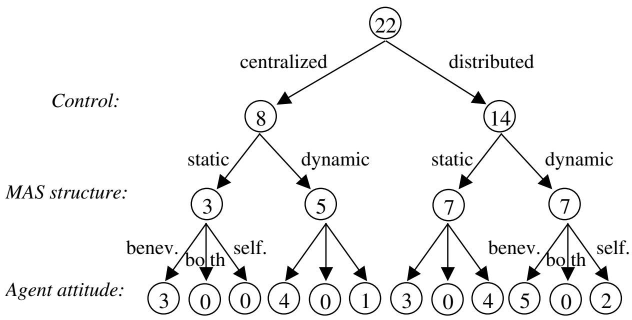

Fig. 4. Number of approaches to automation systems.

Regarding the maturity, the vast majority of the approaches surveyed have just reached the level of conceptual proposal (30%) or simulation with limited or artificial data (53%). An obvious danger with simulation experiments based on artificial or partial data is that abstractions are made that simplifies the problem to a point where the results are not relevant for real-world problems. The table below illustrates how the maturity of the projects has developed through the years, i.e., presenting the number of projects found per year and maturity level. The most recent publication found for each project is included. As can be seen, only one deployed system could be found (Table 2).

In two thirds of the approaches surveyed, agents are applied to solve problems without considering current or alternative approaches to solve these problems. Of those that actually are making comparisons, the majority make only qualitative comparisons. The alternative approaches regarded in the papers are, e.g., for traffic management: evolutionary algorithms, knowledge-based systems, neural networks, fuzzy systems; and for transport scheduling: classical mathematical and operations research methods, i.e., mainly centralized approaches. In Table 3, the number of approaches per evaluation and maturity level is presented.

Table 2
Results: maturity level over the years

Maturity	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
1				1		1	1			2	5	7		
2.1.1	1							1		3	3	1	3	1
2.1.2				1							1			1
2.2.1		1			1			5	1	2	1	1	1	
2.2.2	1						1			1	2	1		
3.1									2			1		
3.2														
4											1			

Table 3
Results: maturity and evaluation level

Maturity	Evaluation comparison			
	None	Qualitative	Quantitative	Both
Conceptual approach	15	2		
Partial scale simulation with fictive data	9	1	2	1
Full scale simulation with fictive data		2	1	
Partial scale simulation with real data	8	3		2
Full scale simulation with real data	2	1	2	1
Field experiment limited scale	2	1		
Field experiment full scale				
Deployed system				1
Total	36	10	5	5

Appendix A. Survey results

Paper	Problem description			Approach				Results	
	Domain	Mode	Time horizon	Usage	Control	MAS structure	Agent attitude	Maturity	Evaluation comparison
Budenske et al. (2001)	Transport	Air	Operational	Automation	Centralized	Dynamic	Both	1	None
Perugini et al. (2004)	Transport	All	Tactical	DSS	Distributed	Dynamic	Selfish	2.2.1	Both
Zhu et al. (2000)	Transport	Air	Tactical	DSS	Distributed	Static	Benevolent	3.1	Qualitative
Böcker et al. (2001)	Transport	Rail	Tactical	DSS	Centralized	Static	Benevolent	2.2.1	None
Sjöland et al. (2002)	Transport	Rail	Tactical	DSS	Centralized	Static	Benevolent	1	None
Bouzid (2003)	Transport	Road	Tactical	DSS	Distributed	Dynamic	Benevolent	1	Qualitative
Fischer et al. (1999)	Transport	Road	Tactical	DSS	Distributed	Dynamic	Benevolent	2.1.1	Both
Kohout and Erol (1999)	Transport	Road	Tactical	DSS	Distributed	Dynamic	Selfish	2.2.1	Both
Sandholm (1993)	Transport	Road	Tactical	Automation	Distributed	Dynamic	Selfish	2.2.1	Qualitative
Sawamoto et al. (2002)	Transport	Road	Tactical	DSS	Distributed	Dynamic	Benevolent	2.1.2	Qualitative
Buchheit et al. (1992)	Transport	Intermodal	Operational	Automation	Distributed	Static	Selfish	2.1.1	None
Bürckert et al. (2000)	Transport	Intermodal	Operational	DSS	Distributed	Dynamic	Selfish	2.2.1	None
Dong and Li (2003)	Transport	Intermodal	Tactical & Operational	DSS	Distributed	Static	Selfish	1	None
Funk et al. (1999)	Transport	Intermodal	Tactical & Operational	DSS	Distributed	Dynamic	Selfish	2.2.1	None
Proshun et al. (2003)	Transport	Intermodal	Strategic	DSS	Distributed	Dynamic	Benevolent	1	None
Bergkvist et al. (2005)	Transport	Intermodal	Strategic	DSS	Distributed	Static	Both	2.1.1	None
Abouaïssa et al. (2002)	Transport	Intermodal	Strategic & Tactical	DSS	Distributed	Dynamic	Benevolent	1	None
Zhu and Bos (1999)	Transport	Intermodal	All	Auto	Distributed	Dynamic	Benevolent	2.2.1	None
Burstein et al. (2000)	Transport Terminal	Air	Operational	Automation	Centralized	Dynamic	Benevolent	3.1	None
Rizzoli et al. (2002) and Rizzoli et al. (1999)	Transport Terminal	Intermodal	Tactical	DSS	Centralized	Dynamic	Selfish	2.2.1	None
Allo et al. (2001)	Traffic	Air	Operational	Auto	Distributed	Dynamic	Benevolent	2.1.1	None
Callantine et al. (2003)	Traffic	Air	Operational	Both	Centralized	Dynamic	Benevolent	2.1.1	Quantitative
Findler and Lo (1991) and Findler and Elder (1995)	Traffic	Air	Operational	Automation	Distributed	Dynamic	Selfish	2.1.2	Quantitative
Iordanova (2003)	Traffic	Air	Operational	DSS	Distributed	Dynamic	Benev	1	None
Košecká et al. (1997) and Tomlin et al. (1997)	Traffic	Air	Operational	DSS	Distributed	Dynamic	Selfish	1	None
Ljungberg and Lucas (1992)	Traffic	Air	Operational	DSS	Centralized	Dynamic	Benevolent	2.2.2	None
Nguyen-Duc et al. (2003)	Traffic	Air	Operational	DSS	Centralized	Dynamic	Benevolent	1	None
Painter (2002)	Traffic	Air	Operational	Automation	Centralized	Dynamic	Benevolent	2.1.1	None

(*continued on next page*)

Appendix A (*continued*)

Paper	Problem description			Approach				Results	
	Domain	Mode	Time horizon	Usage	Control	MAS structure	Agent attitude	Maturity	Evaluation comparison
Wollkind et al. (2004)	Traffic	Air	Operational	DSS	Distributed	Dynamic	Selfish	2.1.1	None
Vilaplana and Goodchild (2001)	Traffic	Air	Operational	Auto	Distributed	Static	Selfish	2.1.1.	None
Wangermann and Stengel (1996) and Wangermann and Stengel (1998)	Traffic	Air	Operational	DSS	Distributed	Dynamic	Selfish	1	Qualitative
Blum and Eskandarian (2002a) and Blum and Eskandarian (2002b)	Traffic	Rail	Tactical	DSS	Centralized	Static	Benevolent	2.2.1	None
Brewer and Plott (1996)	Traffic	Rail	Tactical	DSS	Distributed	Static	Selfish	2.2.1	None
Cuppari et al. (1999)	Traffic	Rail	Operational	DSS	Centralized	Dynamic	Benevolent	2.2.1	Qualitative
Fernández et al. (2002)	Traffic	Rail	Operational	DSS	Distributed	Dynamic	Benevolent	1	None
Parkes and Ungar (2001)	Traffic	Rail	Tactical	Automation	Distributed	Static	Selfish	2.1.1	Quantitative
Törnquist and Davidsson (2002)	Traffic	Rail	Operational	DSS	Distributed	Static	Benevolent	1	None
Fernández et al. (2004)	Traffic	Road	Operational	DSS	Distributed	Dynamic	Benevolent	2.1.1	None
Hernández et al. (2002) InTRYS	Traffic	Road	Operational	DSS	Centralized	Static	Benevolent	4	Both
Hernández et al. (2002) TRYS A_2	Traffic	Road	Operational	DSS	Distributed	Static	Selfish	2.2.2	Both
Choy et al. (2003)	Traffic	Road	Operational	Automation	Distributed	Static	Benevolent	2.2.2	Quantitative
Adler et al. (2005)	Traffic	Road	Operational	Both	Distributed	Dynamic	Benevolent	2.1.2	Qualitative
Balbo and Pinson (2001)	Traffic	Road	Operational	DSS	Distributed	Static	Selfish	2.2.1	Qualitative
France and Ghorbani (2003)	Traffic	Road	Operational	Automation	Centralized	Static	Benevolent	2.2.1	None
Garcia-Serrano et al. (2003)	Traffic	Road	Operational	DSS	Distributed	Static	Benevolent	3.1	None
van Katwijk et al. (2004)	Traffic	Road	Operational	Automation	Distributed	Dynamic	Benevolent	2.1.1	Qualitative
van Katwijk and van Koningsbruggen (2002)	Traffic	Road	Tactical	Automation	Distributed	Static	Selfish	1	None

Goldsmith et al. (1998)	Terminal	Road	Operational	Automation	Distributed	Dynamic	Benevolent	2.2.2	None
Itmi et al. (1995)	Terminal	Sea	Operational	Automation	Centralized	Static	Benevolent	1	None
Lee et al. (2002) and Yi et al. (2002)	Terminal	Sea	Tactical	DSS	Centralized	Static	Benevolent	2.1.1	None
Carrascosa et al. (2001) and Rebollo et al. (2001)	Terminal	Sea	Operational	Automation	Centralized	Static	Benevolent	1	None
Thurston and Hu (2002)	Terminal	Sea	Operational	Automation	Distributed	Static	Benevolent	2.1.1	None
Degano et al. (2001) and Degano and Pellegrino (2002)	Terminal	Intermodal	Operational	Automation	Centralized	Dynamic	Benevolent	2.2.2	Quantitative
Gambardella et al. (2001) and Gambardella et al. (1998)	Terminal	Intermodal	Tactical	DSS	Distributed	Static	Benevolent	2.2.2	Qualitative
Henesey et al. (2003a)	Terminal	Intermodal	Strategic	DSS	Distributed	Static	Selfish	1	None
Henesey et al. (2003b)	Terminal	Intermodal	Operational	Automation	Distributed	Static	Benevolent	1	None

5. Conclusions

While producing the survey we have identified a number of positive aspects of the current state of agent-based approaches to logistics:

- Many different approaches have been suggested and investigated.
- Many of the logistics problems that have been studied have characteristics that closely match those of an ideal agent technology application very well.
- Especially in the areas of air and road traffic management agent technology seems to have contributed significantly to the advancement of state-of-the-art.

However, there are also some things that can be improved:

- The maturity of the research; few fielded experiments have been performed and very few deployed systems could be found.
- The suggested agent-based approaches are often not evaluated properly; comparisons with existing techniques and systems are rare. Both qualitative assessments explaining the pros and cons of agent technology compared to the existing solutions, and quantitative comparisons to these solutions based on experiments, are desired.
- Some problem areas seem under-studied, e.g., the applicability of agent technology to strategic decision-making within transportation logistics.

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